AN EXPERIMENTAL BENCHMARKING STUDY ON HYBRID COASTAL DUNE REINFORCEMENT VARIANTS

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INTRODUCTION
Besides the natural protection of coastal dunes against storm surges (Mehrtens et al., 2023), blue-grey-hybrid dune structures play a key role in strengthening the protective mechanism of dunes against erosion, while imitating their natural landform appearance and function (Nordstrom 2019). Although artificial dunes with hybrid core enhancements are widespreadly implemented along many coasts worldwide (Winters et al., 2020), limited work addressed the effectiveness and potential enhancement of specific dune reinforcement strategies in a comparative fashion. An exception to this statement is the work by Figlus et al (2015), who conducted a series of experiments with three incorporated dune cores: a T-wall, a clay levee and an armour stone revetment. Nonetheless, a benchmark study on the efficacy and comparative performance of hybrid dune reinforcement strategies, with an identical parameter frame remains unavailable to date.

OBJECTIVES AND NOVELTY
This work hence presents a new comprehensive series of experiments aimed to systematically assess multiple variants for blue-grey-hybrid dune reinforcement in terms of their potential to reduce dune erosion and failure under different storm surge regimes.

METHODS
Physical dune experiments with four blue-grey-hybrid dune reinforcement variants were conducted in a wave flume. A uniform length scale of 1:7, applying Froude similitude for a dune model composed of sand with a grain size d_{50} of 0.144 mm, served as the basis for the test series (see Fig. 1a and 1b). From this homogenous reference dune model (see Fig. 1c), various hybrid dune reinforcements with fixed integrated structures installed at different positions inside the dune were investigated under specific hydrodynamic load conditions, leading to widely accepted load regimes after Sallenger (2000). A selection of tested reinforcement types is compiled in Fig. 1d to 1j, with detailed design explanations in Tab. 1. Each test (with a duration of 113 min) was performed using irregular waves (JONSWAP spectra with $\gamma = 3.3$) with combinations of two water depths ($d_1 = 0.5$ m and $d_2 = 0.56$ m) and two wave conditions ($H_{s,1} = 0.14$ m and $T_{p,1} = 2.3$ s; $H_{s,2} = 0.18$ m and $T_{p,2} = 2.8$ s) to simulate three different collision and overwash regimes. The flume was equipped with several wave gauges to control incident wave conditions. A novel solid-state 3D Lidar sensor has been used to record spatio-temporal dune profile development at a sampling rate of 0.7 Hz.

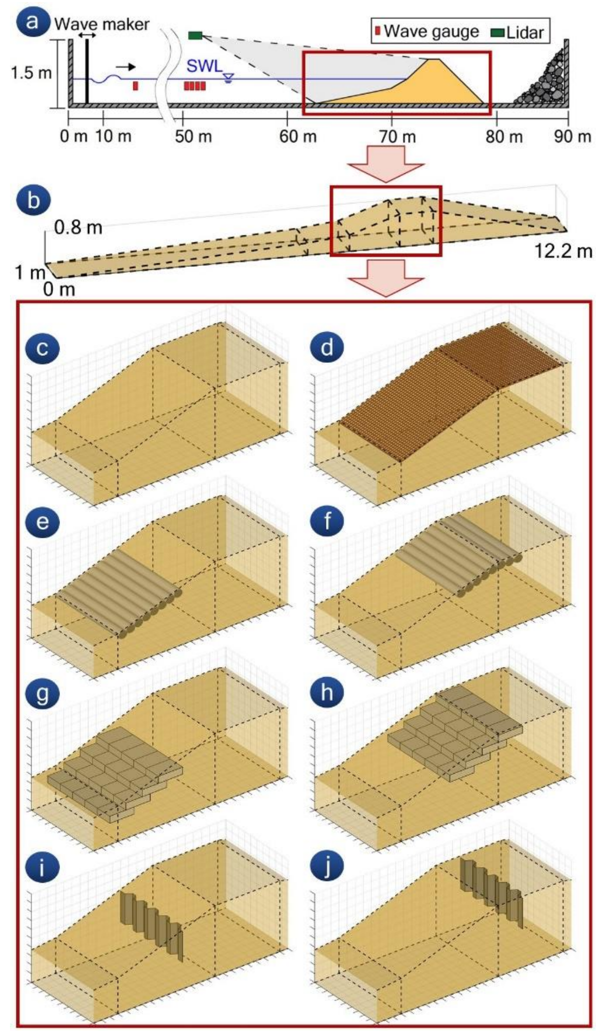

Figure 1 – Experimental model setup, with: a) schematic setup overview; b - c) reference dune model; d – j) tested reinforcement variants with respective installation positions.

RESULTS
Final dune states and profiles are shown in Fig. 2 and 3 for all tested dune model setups under a collision regime with $d_1 = 0.5$ m, $H_{s,2} = 0.18$ m and $T_{p,2} = 2.8$ s. The homogeneous reference dune has been significantly eroded over more than half of the dune crest, causing major sand deposition on the dune lee side (see Fig. 2a and 3a). Despite the built-in coir fiber mat, distinct dune

Table 1: Overview of tested reinforcement variants and their installation positions.

Figure	Variant	Installation position
Fig. 1d	Coir fiber mat	Buried below the surface
Fig. 1e & Fig. 1f	Sand-filled geotubes	Buried in dune lee slope and at dune crest
Fig. 1g & Fig. 1h	Multiple sand-filled geobags	Buried in dune lee slope and at dune crest
Fig. 1i & Fig. 1j	Steel sheet pile	Installed in dune lee slope and at dune crest

erosion occurred, transporting sediment through the meshes of the mat (see Fig. 3b). However, compared to the reference dune, the amount of eroded sediment has been diminished by the mat. The geotubes installed at the lower slope section ensured that erosion exclusively occurred in the upper frontal dune area (see Fig. 3c). Thereby, all geotubes maintained position stability (see Fig. 2c) as the lower geotubes remained buried for the entire test duration, preventing the upper geotubes from sliding. In contrast, the geotubes installed at the dune crest did not remain position-stable (see Fig. 2d) as a consequence of scouring below the lowest geotube and subsequent sliding of several geotubes, leading to increased erosion along the dune slope (see Fig. 3d). The geobags installed at the slope remained equally position-stable as the geotubes (see Fig. 3e). Nevertheless, an increased dune erosion occurred as the four geobag layers were installed at a comparatively lower maximum elevation. The geobags installed at the dune crest all sagged into the dune by approximately 10 cm (see Fig.

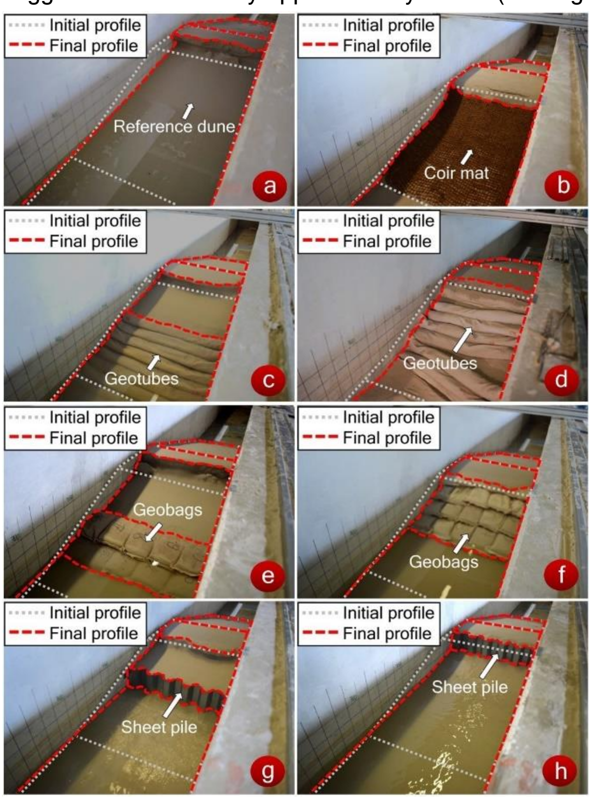

Figure 2 - Final state overview of the reference test (a) and all tested reinforcement variants (b - h).

3f). In contrast to the geotubes, the geobags did not slide down the lee side (see Fig. 2f) and reduced the overall erosion. The fixed installed sheet pile provided an impermeable barrier at both positions. In the case of the variant mounted at the dune slope, minor erosion occurred at the upper frontal dune area (see Fig. 2g). Moreover, the slope area in front of the sheet pile has been eroded, causing scouring above the sheet pile toe (see Fig. 3g). Similarly, the erosion for the second sheet pile installation was limited to the dune area in front of the structure (see Fig. 3h). For both installation positions, the sheet pile length was sufficient to avoid undercutting.

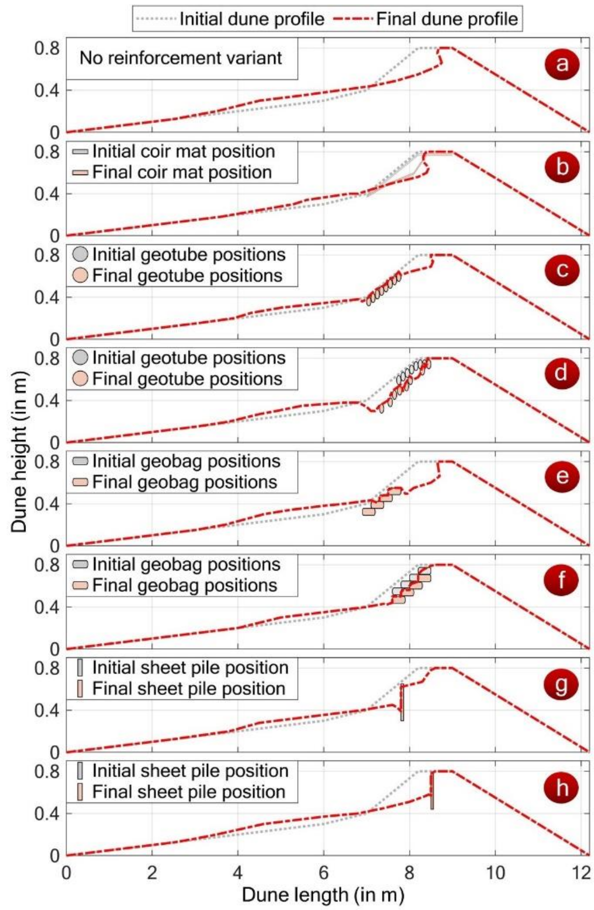

Figure 3 - Final cross-section dune profiles of the reference test (a) and all tested reinforcement variants (b - h).

DISCUSSION & OUTLOOK

The experimental results show the protective effects of four reinforcement variants under a collision load regime. Ongoing analyses on temporal dune developments will further contribute to comprehend erosional processes as well as the failure of specific variants (e.g. sliding of geotubes). Moreover, the pending evaluation of test series under more severe overwash conditions will provide a broader assessment of the protection potential of all tested variants and their installation positions.

REFERENCES

Due to space limitations, references mentioned herein were not provided.